The Effect of Stochastic Noise on Predictability

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LONG-TERM GOAL

Our long-term goal is to improve the accuracy of numerical prediction models of weather and climate. We shall concentrate on sources of prediction error involving interactions between physical phenomena having different timescales.

OBJECTIVES

We examine how inadequate representation of rapidly-varying (i.e., stochastic) atmospheric effects in General Circulation Models (GCMs) can systematically affect prediction on a variety of scales, and how errors arising from this inadequacy may be ameliorated. Concurrently, we develop useful, efficient and accurate methods of accounting for these systematic effects of stochastic forcing, and also provide methods for estimating the spread of ensemble predictions taking into account multiplicative stochastic effects.

APPROACH

We approach the problem both analytically and numerically. Simple barotropic models present cases that are nontrivial, yet simple enough to solve analytically, and we use these models to identify and solve some of the numerical problems that will arise in realistic, more complex models. We intend to apply our results to studying the impact of stochastic forcing in more complete models, culminating

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with long runs of stochastically forced, full-fledged GCMs and numerical weather prediction (NWP) models.

Although routinely ignored in current models, the theory of stochastic white noise is well known and analytic solutions are available, at least in principle. We have evaluated the effect of white stochastic forcing on the mean response of a global barotropic model to steady forcing. In addition, we have considered the more realistic problem of stochastic colored noise forcing, deriving analytic estimations of the systematic change in the mean response, and have compared these analytic approximations with results from stochastically forced numerical models.

Theorems appropriate to numerical analysis of deterministic systems generally do not carry over into their stochastic counterparts, and the numerical generation of stochastically forced systems required us to confront purely numerical problems. We spent considerable effort investigating the choice of time step and the optimal length of integration time for these stochastic models.

WORK COMPLETED

We have completed numerical work on the steadily forced barotropic vorticity equation with stochastic variations in the basic state. We also completed analysis of a similar system with stochastically varying friction.

We considered the robustness of the white-noise approximation when the pertinent assumptions were not strictly valid, and derived analytic expressions for the expected mean response to colored-noise forcing with widely different timescales.

We considered the effect of numerical methods on the accuracy of accumulated statistics and documented our experience.

RESULTS

We have obtained three different kinds of results, each of which will be exposed in a separate publication.

Analytic expressions for the mean effect of multiplicative white noise forcing were found to agree well with numerical results. We found that stochastic variations in the basic state of a steadily forced barotropic vorticity model would cause Rossby waves to be more strongly damped than in the deterministic case, in contradiction to some previous conjectures that multiplicative noise would be unconditionally destabilizing. On the other hand, stochastic variations in frictional damping did indeed have a destabilizing effect.

The fact that stochastic variations often do not decay on timescales much faster than those of the weather systems to be predicted required us to consider how robust the white noise approximations are. We developed a general formula for the drift in mean response of a steadily forced linear system due to stochastic perturbations with timescales ranging from much faster than deterministic timescales to much slower than deterministic timescales. We showed that this general formula is rigorously correct in the fast- and the slow-noise limits, and numerical simulations verified this. Results from numerical simulations also agreed with this general formula in the regime where neither the fast- nor the slow-noise limit obtains.

We found that the ease with which non-deterministic systems can be accurately generated numerically decreased drastically with the ratio of deterministic to stochastic timescales, with all of our non-deterministic systems requiring much shorter time steps and much longer integration times than their deterministic counterparts. We generally found better results when the stochastic forcing was generated with a different time step than that used in the numerical prediction model of the physical system.

IMPACT/APPLICATION

Our research will have a direct impact on ensemble weather and climate prediction. We have found that we needed to use numerical methods and criteria for choice of time step and integration time that are generally not used in the numerical modeling community. The methods currently used in stochastic numerical models are likely to be highly inaccurate, and our work helps to 1) quantify how inaccurate those methods may be and 2) offer alternatives to them in order to improve the accuracy of numerical prediction models.

TRANSITIONS

The analytical work we have done has proven to be interesting to the general stochastic modeling community, and we have been invited to discuss our work at a workshop hosted by the Centre Européen de Calcul Atomique et Moléculaire, in Lyon, France, next summer. We are also engaged in scientific discourse with scientists at the Ilya Prigogine Center for Statistical Mechanics, at the Department of Physics, The University of Texas at Austin.

RELATED PROJECTS

The methods developed in this project are also being applied to determine sensitive areas of diabatic forcing in the atmosphere that lead to large responses in specified remote regions around the globe. A combination of empirical and numerical modeling approaches is being taken to this problem using global observational datasets and a hierarchy of dynamical models. The PI and Co-PI’s are collaborating with Dr. Gilbert Compo, Dr. Michael Alexander, Dr. Joseph Barsugli and Mr. Christopher Winkler, all of the Climate Diagnostics Center, on these related projects.